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Preliminary Assessment of the Potential Impact of Fog Oil Smoke on Selected Threatened and Endangered Species

by
Lowell L. Getz
Keturah A. Reinbold
David J. Tazik
Timothy J. Hayden
Debra M. Cassels

The use of smokes and obscurants is a critical component of military tactical training. Fog oil is the most commonly available smoke/obscurant material used during training exercises. Exposure to smokes and obscurants is perceived to constitute a potential negative impact on individuals or populations of threatened and endangered species present in training areas.

Currently, the data are inadequate to provide an accurate assessment of the potential impact of smokes and obscurants, as currently used by the military, on threatened and endangered species occupying training installations.

This research provides a preliminary assessment of the environmental impacts of fog oil smoke used in training exercises based on available data and information (and assumptions stated in the report), especially as they might affect threatened and endangered species. This research also identifies specific data and information gaps that should be the focus of future research efforts. Only by obtaining such data and filling such gaps can land managers ensure compliance with Federal regulations while minimizing constraints on training programs.

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Foreword

This study was conducted for the Deputy Chief of Staff for Operations and Plans (DCSOPS) under Reimbursable Order E87930341, dated June 1993, Work Unit KW3 "Effects of Army Training on the Management of Threatened and Endangered Species on Army Training Lands and Ranges." The technical monitor was Tony Rekas, DAMO-TRO.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL co-principal investigators were Dr. David J. Tazik and Dr. Keturah A. Reinbold. Dr. Lowell L. Getz is Professor of Ecology in the Department of Ecology, Ethology, and Evolution at the University of Illinois, Urbana, IL. Timothy J. Hayden is a USACERL Research Ecologist. Debra M. Cassels is a Research Associate, Colorado State University. Dr. David J. Tazik is Acting Chief, CECER-LL-N; Dr. William D. Severinghaus is Operations Chief, CECER-LL; and William D. Goran is Chief, CECER-LL. The USACERL technical editor was Gloria J. Wienke, Technical Resources Center.

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COL James T. Scott is Commander and Acting Director, and Dr. Michael J. O'Connor is Technical Director of USACERL.

Contents

1 Introduction

Background

There is a long history of using smoke screening in military operations (Muhly, 1983). Proper use of smokes and obscurants is estimated to reduce troop exposure to enemy fires by up to 60 percent (LTC Harry Sutton, TRADOC Smoke Inte-gration Proponency Office, Fort McClellan, AL). Effective integration of smoke screens with deployment of combat maneuver units requires close coordination. Thus, use of smokes and obscurants is a critical component of tactical training.

A major problem facing the military in meeting its training objectives is the requirement to comply with environmental regulations during training exercises (COL R. E. Thornton; Memorandum, U.S. Army Chemical School, Fort McClellan, AL, 1 Jun 1994). Compliance includes minimizing adverse impacts on individuals or populations of threatened and endangered species present in training areas. Exposure to smokes and obscurants is perceived to constitute such a potential negative impact.

A variety of materials are available for use as smokes and obscurants, including white and red phosphorous, hexachloroethane (HC), diesel fuel, fog oil, and infrared (IR) obscurants, such as brass flakes and graphite powder. Of these, fog oil (Standard Grade Fuel [SGF] No. 2, a middle distillate product of crude petroleum, drawn from stocks of raw industrial lubricating oil; similar in viscosity to S.A.E. 20 motor oil) is the most commonly available smoke/obscurant material used in general smoking during training exercises. Diesel fuel is no longer used as a vehicle fuel and thus is not available for vehicle engine exhaust smoke system (VEESS) smoking. In a VEESS, diesel fuel was diverted from the fuel tank onto the hot engine manifold and disseminated as a vaporized smoke cloud with the exhaust. Currently, JP8 is the only motor fuel in the Army inventory. JP8 cannot be used in VEESS smoking because of the potential for flashing and the danger to vehicle crews from resulting fires. HC smoke is not used for large scale smoking in tactical training exercises because of human safety problems. White and red phosphorous smokes generally are delivered by munitions and thus cannot be used in close support of tactical training exercises; most phosphorous smoke is released in artillery impact areas. Colored smokes, released from

grenades, are used only as marking materials; as such, the quantities released are minimal. There is very little current use of IR screening materials in training. Brass flake grenades are deployed only occasionally in training exercises. Graphite is used very sparingly because of the expense incurred in its use.

Due to human health and environmental concerns, several laboratory studies have been conducted regarding toxicological effects of various smokes and obscurants on given species, dating back to the 1940's (as summarized in Liss-Suter and Villaume 1978a, 1978b; Muhly 1983; Shinn et al. 1985, 1987; Palmer 1990; Driver et al. 1992). In addition, models have been generated to predict environmental concentrations and fate of various types of smokes (Liss-Suter and Villaume 1978a; Muhly 1983; Shinn et al. 1987; Driver et al. 1992). In spite of these efforts, there are inadequate data to provide an accurate assessment of the potential impact of smokes and obscurants, as currently used by the military, on threatened and endangered species occupying training installations. The experimental conditions in most toxicological studies were much higher than predicted concentration/duration of exposure that would be incurred during training exercises. Further, the models have not been field-tested adequately; we still do not know the concentrations of smokes and obscurants actually encountered by given species. Consequently, to comply with Federal regulations regarding avoiding negative impacts on threatened and endangered species, training programs must be conducted under worst-case scenarios. Accordingly, use of smokes and obscurants is severely curtailed on most combat training installations. This places considerable constraints on training programs, and, in turn, seriously restricts the ability of units to achieve desired combat readiness (COL F. E. McFarren; Memorandum, HQ XVIII Airborne Corps, Fort Bragg, NC, 19 Feb 1992).

Objectives

The objectives of this research are to (1) preliminarily assess the environmental impacts of fog oil used in training exercises based on available data and information (and assumptions stated in the analyses that follow), especially as they might affect threatened and endangered species, and (2) identify specific data and information gaps that should be the focus of future research efforts. Only by obtaining such data and filling such gaps can land managers ensure compliance with Federal regulations while minimizing constraints on training programs.

Approach

In this report we evaluate the available data regarding (1) typical (or desired) use of smokes and obscurants in tactical training, (2) estimated environmental concentrations, (3) estimated toxicological effects, and (4) the natural history of selected threatened and endangered species. We (1) assess the adverse effects that might be incurred by each species, (2) specify the conditions that place the species at risk, and (3) identify the specific data that are needed to test these assessments.

Simplifying assumptions are made to project potential acute effects of exposure to fog oil on threatened and endangered species. By assuming relatively simple, usually homogeneous, and static conditions and using general smoke dispersion models, straightforward calculations of exposure and potential effects can be projected by correlating the calculated exposure concentrations with effects concentrations reported in the literature for some species. However, it must be kept in mind that the data are not for the species of concern and are primarily for mammals, except for some feeding studies with birds. These assumptions do not include modifications of exposure resulting from factors such as localized meteorological conditions or microscale variations in wind direction or speed, temperature, or convection currents. Similarly, effects of habitat and terrain conditions on smoke dispersion are not addressed other than movement of smoke into hills adjacent to level terrain where the smoke is being generated. Assumptions for specific projected scenarios are stated throughout the text where each scenario is presented and discussed.

Scope

In this report we limit our analyses to the potential effects of fog oil on threatened and endangered species since (1) fog oil currently is the most commonly used smoke material in training exercises and will continue to be such in the foreseeable future, (2) there are specific models available regarding potential environmental concentrations of fog oil during a smoking operation, (3) the spatial coverage of the fog oil smoke screen cloud generated during a smoking operation is more readily defined than for other smoke materials, and (4) extensive data are available as to the toxicological effects of fog oil and related petroleum products on a variety of species.

This report is an initial evaluation under projected simplified conditions of potential effects of fog oil smoke on selected threatened and endangered species that occur on Army installations where fog oil smoke is or may be generated. Several bird species and some reptiles and amphibians are considered. No individual plant species are addressed in this evaluation. The report addresses potential immediate, direct, acute

effects on selected threatened and endangered species resulting from exposure to fog oil smoke. It does not consider potential chronic effects (such as reduced reproduction) from repeated or long-term exposure. Delayed effects from direct exposure to fog oil or from consumption of contaminated food are not addressed other than mortality from possible sufficient accumulation in food. Indirect effects such as reduction in food organisms or damage to habitat for threatened and endangered species are not addressed in this report.

2 Methods

Estimated impacts of fog oil smoke on threatened and endangered species were derived by the following:

1. extrapolations from published models that estimate concentrations of fog oil in the air and potential deposition on the substrate (vegetation, bark of trees, and water),
2. identification of critical life history characteristics of the species that affect the degree of exposure of individuals to fog oil smoke,
3. extrapolations from toxicological studies on the most appropriate species for which data are available,
4. personal interviews with Army personnel and others familiar with smoking operations, and
5. observations of fog oil smoke screening exercises at Fort McClellan, AL (observations by L. L. Getz).

This report addresses only potential *short-term* or *acute* effects of fog oil smoke on given threatened and endangered species; it does not attempt to evaluate *long-term* or *chronic* environmental effects. An overall evaluation of the effects on threatened and endangered species should, however, include potential chronic effects, especially as might accrue from long-term exposure of individuals and populations to fog oil residue and its transformation products. Preliminary studies by Schaeffer et al. (1986) suggested that plants and animals exposed to smokes potentially are at risk of changes such as decreased fertility, changes in energy production, decreased survivability, and increased toxic effects. However, these authors indicated it may take years or decades for ecological systems to exhibit obvious symptoms of toxic stress when subjected to chronic exposures to smokes and obscurants. An accurate evaluation of chronic effects is not possible at this time. Available data on formation and accumulation of fog oil and its transformation, or degradation, products presumed to be released during typical, short-term smoking exercises are inadequate to predict chronic effects on threatened and endangered species. The assumptions regarding short-term effects represent the best estimates of potential effects of fog oil smoking exercises on threatened and endangered species, given the inadequacy of the available data.

The following threatened and endangered species are considered in this report: Red-Cockaded Woodpecker (*Picoides borealis*), Eastern Indigo Snake (*Drymarchon corais couperi*), Gopher Tortoise (*Gopherus polyphemus*), Golden-cheeked Warbler (*Dendroica

chrysoparia), Black-capped Vireo (*Vireo atricapillus*), Gray Bat (*Myotis grisescens*), and Indiana Bat (*Myotis sodalis*). In addition, we have included an evaluation of potential effects of fog oil on some candidate species that may soon be listed as threatened or endangered, including Sage Grouse (*Centrocercus urophasianus phaios*), Bachman's Sparrow (*Aimophila aestivalis*), Flatwood Salamander (*Ambystoma cingulatum*), and the Striped Newt (*Notophthalmus perstriatus*). All these species occur in a variety of geographic regions of the United States, occupy several different habitat types, and represent a number of different taxa and guilds within the same taxonomic group, as in the case of the birds.

There are a number of threatened and endangered, as well as candidate, species of plants on Army installations. However, there is inadequate information regarding the effects of fog oil on plants to estimate accurately the potential acute effects of smoke screening exercises on populations of these plant species (Cataldo et al. 1989). We provide only a generalized appraisal of the potential effects of fog oil on threatened and endangered plant species.

3 Results and Discussion

Environmental Concentrations

Assumptions

Several assumptions were made as a basis for predicting potential impacts of fog oil on given species:

1. a 2-hour smoking exercise,
2. a release rate of 80 gallons (302 Liters) per hour per generator, resulting in a total release of 160 gal (604 L) per generator, and
3. an area 1 kilometer wide and 1 kilometer deep is smoked.

According to Field Manual (FM) 3-50 and interviews with personnel familiar with smoke screening operations, most smoke training exercises last 30 to 90 minutes. We have used a 2-hour exercise to include the time it takes for the smoke cloud to disappear following termination of smoking under temperature inversion conditions, which is the worst-case scenario for dispersion of fog oil clouds. A release of 80 gal (302 L) per hour is in excess of the estimated 50 gal (189 L) total release by the M 157 generator, the model currently in use by active units, during a smoking exercise. However, the best models predicting resulting environmental concentrations (Driver et al. 1992) were based on a release rate of 80 gal (302 L) per hour. Again, using the six models discussed by Driver et al. (1992) presents a worst-case scenario. A chemical company can lay down a cloud 500 to 1500 meters wide and up to 3000 m deep, depending on the tactical situation. Most situations call for a smaller area to be smoked. The 1000- by 1000-m area into which the complete release of fog oil is concentrated provides a reasonable estimate of an area smoked during a typical smoking exercise.

Estimated Environmental Concentrations

The projections of the six models provided by Driver et al. (1992) were used to estimate the maximum concentrations of fog oil expected to occur in the air, on the surface of objects, including the vegetation and trunks of trees, and in water. Other authors have presented estimates of fog oil concentrations in the air and deposition concentrations on the substrate (Liss-Suter and Villaume 1978a; Muhly 1983; Shinn et al. 1987).

Most of these estimates do not incorporate the complexity of atmospheric conditions affecting dispersion and deposition of the fog oil as do the models presented by Driver et al. (1992). All the models, however, including those of Driver et al. (1992), are based on releases over open areas; as such, they may not predict accurately the conditions within forested areas. Table 1 lists predicted concentrations (potential average concentrations and ranges derived from the six models) for simulated specific sets of atmospheric conditions. Varying distances from the source (100 m, 200 m, 500 m, and 1000 m) allow for an estimated range of effects on animals occurring within the area encompassed by a typical tactical smoking exercise. Because of the almost continuous movement of the smoke-generating vehicles during an exercise, it is not practical to estimate fog oil concentrations any nearer the generator. The density of the fog oil cloud appears rather uniform over the first 100 m of the smoked area. In addition, the models of Driver et al. (1992) do not provide estimates of fog oil concentrations closer than 100 m from the source. Air concentrations and surface deposition values were calculated directly from the model graphs.

The Flatwood Salamander and the Striped Newt are the most likely candidate aquatic animals to be affected by fog oil in the Southeast. Both species use shallow temporary ponds. When calculating aquatic concentrations, the average depth of the temporary ponds is assumed to be 1 m. To estimate concentrations of fog oil in the water, the predicted concentrations per cubic meter (mg/m^3) of water area have been assumed to be the same as the depositions per square meter (mg/m^2) of surface area of water. The concentrations would become greater as the water evaporates and the ponds become more shallow.

The values given for air concentrations will apply only for the period of the smoking operation. Observations indicate that essentially all the visible fog oil cloud in the air will have dissipated from the site within 5 minutes following termination of the smoking exercise. The actual time required for the smoke to dissipate following any given exercise depends on wind speed, humidity, and presence of lapse conditions (air temperatures decrease at increasing distance from the surface) or temperature inversions (air temperatures increase at increasing distance from the surface). Inhalation effects from a given smoking exercise are predicted to be transitory, at most 2 hours in duration. This assumption is based on observations of dissipation. Thus, inhalation and dissipation need to be verified together under a variety of atmospheric, terrain, and vegetation conditions. On a given installation there typically would be approximately six to eight 1-week long training periods per year involving smoke screening. Smoke screens would be produced about four times each week. Except for the smoke school, seldom would smoke be deployed more than once at the same site (LTC Harry Sutton, Fort McClellan, AL, professional discussion). Unfortunately,

Table 1. Estimates of fog oil concentrations resulting from typical smoke screening operations at given distances from the source.[1]

Air Concentration[2]	Distance (meters)	Average (mg/m³)	Range (mg/m³)
	100 200 500 1000	64 56 46 13	25 - 102 8 - 105 1.3 - 90 0.8 - 25
Aquatic Concentrations[3]	**Distance (meters)**	**Average (mg/m³)**	**Range (mg/m³)**
	100 200 500 1000	3080 1030 243 101	160 - 6000 960 - 2000 6 - 480 2.4 - 200
Surface Deposition[4]	**Distance (meters)**	**Average (mg/m²)**	**Range (mg/m²)**
At the end of the smoking period	100 200 500 1000	3080 1030 243 101	160 - 6000 960 - 2000 6 - 480 2.4 - 200
1 hour after stopping the smoking	100 200 500 1000	2000 670 158 66	104 - 3900 40 - 1300 3.9 - 312 1.6 - 130
1 week after stopping the smoking	100 200 500 1000	462 154 36.5 15	24 - 900 9 - 300 0.9 - 72 0.4 - 30

[1] The values represent midpoints (average) of the lowest and highest (range) estimated concentrations predicted from models based on the six sets of environmental conditions in Driver et al 1992. The models are based on a 2-hour release at a rate of 80 gal (302L) per hour.
[2] Estimates of concentrations present during the release.
[3] Based on the assumption that all the fog oil released deposits on the surface deposits of the water and becomes incorporated in the water column; pools are assumed to be 1 m deep. Thus surface deposition in mg/m² translates to total concentration in mg/m³.
[4] Total accumulation based on the untested assumption that all the fog oil released deposits from the air into an area 1000 m by 1000 m.

training schedules that involve use of fog oil smoke screening vary among installations and from year to year on a given installation. It is not possible to provide in advance a general estimate of how much, and during what part of the year, given species of threatened and endangered species would be exposed to fog oil. Ability to vary the training schedules to avoid critical exposure periods cannot be predicted. Such variation in training schedules would depend on national needs and commitments of the units involved.

The position of the bottom of the smoke cloud in relation to the surface depends on atmospheric conditions and rate of movement of the generator vehicles. Under

extreme lapse conditions, the cloud may rise rapidly as it drifts downwind from the release point and not intersect the surface. More commonly the cloud extends down to the surface within 5 to 10 m of the generator. When temperature inversion conditions exist, the cloud is likely to be depressed against the surface and remain in low depressions for a long time. The fog oil smoke cloud would also intersect the surface and all above-ground vegetation on elevated terrain features within the smoked site. As such, bark and leaves of shrubs and trees would be in contact with the smoke.

Although the fog oil cloud routinely extends down to the ground surface, there is no evidence that significant quantities of the fog oil deposit from the air onto the surface or vegetation (Muhly 1983, Liljegren, Dunn, and Devaull 1988; Cataldo et al. 1989, Bowers and White 1992; Driver et al. 1992; L. L. Getz, personal observation). The oil droplets are assumed to be so small (0.5 to 1.0 micron) that they remain suspended in the air until such time that the oil evaporates. If these assumptions are true, there would be essentially no deposition of fog oil onto the ground or vegetation. However, if the air contains dust and other particulates or fog upon which fog oil could aggregate, the resulting larger droplets may deposit to the surface. Likewise, rain occurring during the smoking exercise may result in deposition of the fog oil onto the surface. Accordingly, we assume the worst-case scenario—that in which all fog oil deposits on the surface and adheres to the vegetation. If such deposition occurred, fog oil droplets could also adhere to the skin, feathers, and fur of target species and could settle on their food (including insects and other invertebrates) exposed to the smoke.

Even when assuming the worst-case scenario (i.e., that all fog oil droplets deposit on the surface or adhere to vegetation and bark), the predicted concentrations are relatively low (Table 1). It also has been estimated from mathematical models that 30 to 35 percent of the fog oil film would evaporate within 1 hour and 80 to 90 percent within 1 week (Driver et al. 1992). Thus, the residues that might accumulate on surfaces during a single smoking exercise soon may be reduced greatly. However, there are no empirical data to test these predictions. For our assessments, estimates of surface concentrations are provided for conditions immediately following termination of the smoking exercise as well as for 1 hour and 1 week later.

There is presumed to be little or no translocation of fog oil from the dry surface of the leaf litter to within the moist decomposing zone (Driver et al. 1992). Oil adheres tightly to the surface of the leaves, remaining there until evaporating or degrading. However, vehicular traffic over sites onto which fog oil had deposited would tend to mix the fog oil into the substrate. In addition, periods of rain might result in oil being washed deeper into the substrate.

Most oil that deposited onto ephemeral vernal pools would also be expected to remain on the surface rather than being dispersed into the water column. Vanderhorst, Gibson, and Moore (1976) demonstrated that, unless there was extreme turbulence (well in excess of that expected to occur in nature), no fog oil was detectable within the water column. Because of the low probability of significant wave action in small vegetation-surrounded bodies of water, there should be little mixing of the water and oil. The surface film of fog oil would soon evaporate (Aiken and Roberts 1979; Muhly 1983). Anderson et al. (1974) found when there was mixing of the water and oil, some of the petroleum hydrocarbons of No. 2 fuel oil dissolved into water. Lysyj and Russell (1974), on the other hand, concluded that in comparison to fuel oil, very little S.A.E. 20 motor oil (i.e., fog oil) dissolved into water. Accordingly, the predicted aquatic concentrations in this report most likely represent worst-case scenarios. However, if dust and other particulates settle on the surface of pools with an oil film, it is possible that some of the oil could adhere to these particles and sink into the water column. Even if such incorporation of fog oil into the water occurs, Aiken and Roberts (1979) found fog oil to be relatively nontoxic to aquatic organisms.

Atmospheric concentrations of fog oil are dynamic, responding to variation in wind currents, temperature, humidity, and precipitation during and following the smoking exercise. The models do not provide sufficient data to take into account all these effects. Some researchers have presented estimates of environmental concentrations of fog oil resulting from smoking operations, none of which have been verified in the field. Shinn (1987) estimated air concentrations within the area encompassed by a typical smoke cloud to be 5.9 to 8.9 mg/m^3; Liss-Suter and Villaume (1978a) predicted air concentrations of 13 to 2000 mg/m^3, depending on the area covered by a given release of smoke. A model presented by Muhly (1983) predicted air concentrations of 90 to 2000 mg/m^3 at 100 m from the source, 40 to 1000 mg/m^3 at 200 m, 10 to 200 mg/m^3 at 500 m, and 3 to 700 mg/m^3 at 1000 m from the source. Liss-Suter and Villaume (1978a) predicted deposition concentrations of 6 to 60 g/m^2, depending on the total area covered by a single smoke release. Shinn (1987) presented a formula that predicted concentrations of fog oil in water (assuming that deposited fog oil on the water surface became incorporated into the water column) in 1 m deep pools to range from 21 to 32 mg/m^3. The Meteorological Division of Dugway Proving Ground, UT, has also generated models of fog oil concentrations in the air and deposition on the surface, using eight potential sets of conditions (Handbook for Environmental Assessments of Smokes and Obscurants Testing Activities, JTCG/SAWG, 1993). The estimated atmospheric fog oil concentrations are as follow: 100 m, 3.8 mg/m^3; 250 m, 3.5 mg/m^3; 500 m, 2.7 mg/m^3; and 1000 m, 1.2 mg/m^3. Maximum deposition estimates are as follow: 100 m, 13.5 mg/m^3; 250 m, 12.7 mg/m^3; 500 m , 11.2 mg/m^3; 1000 m, 4.3 mg/m^3. Except for those of Muhly (1983) these predicted concentrations are all considerably less than those of Driver et al. (1992) as used in our assessments. Policastro et al.

(1989) and Liljegren et al. (1989) tested a variety of models predicting fog oil concentrations at varying distances from the source. However, these studies do not provide more comprehensive data than those of Driver et al. (1992). The only empirical data regarding actual environmental concentrations of fog oil are those from the preliminary studies of Liljegren, Dunn, and Devaull (1988). They recorded maximum concentrations of 7.7, 3.6, and 2.6 mg/m^3 at 100 m, 200 m, and 400 m, respectively, from the source. We have used the estimates of Driver et al. (1992) rather than those of Muhly (1983) since the former were based on a number of different sets of environmental conditions (temperature, wind speed and vector, air stability conditions). The latter estimates were based only on one worst-case scenario (temperature inversion and less than 5 mph wind speed).

Forest Fires

Forest fires are a natural phenomenon of the pine forests of the Southeastern United States, the habitat of the Red-Cockaded Woodpecker, Bachman's Sparrow, Gopher Tortoise, and Eastern Indigo Snake. These pine forests are frequently referred to as "fire-climax" forests in that without fires, the pines would be replaced by an oak community (Oosting 1956). During presettlement times, natural fires occurred at such frequency as to prevent establishment of oaks. These fires killed the invading oak trees and other understory deciduous trees and shrubs, and suppressed some of the herbaceous vegetation. Current pine forest management programs include extensive controlled burns to prevent replacement of pines by the economically less valuable oaks.

Forest fires result in the formation of extensive smoke clouds comprised of carbon particles and a number of gases. Large quantities of carbon particles are released by all fires. Carbon particle size ranges from < 0.3 micron to > 1.0 micron and the color from white to black (Schaefer 1973), depending on the composition of the inflammable material and the intensity of the burn. Aside from carbon dioxide production by forest fires (Nixon 1990), there is little information regarding the release of gases by forest fires (Vines 1973a). Radke et al. (1978) and Stit, Radke, and Hobbs (1981) recorded substantial release of nitrogen oxides (nitrogen dioxide and nitric oxide) and ozone by forest fires in western Washington; Evans et al. (1974) also provided data regarding the presence of ozone in forest fire smoke. However, these latter studies did not detect the presence of other noxious gases. On the other hand, forest vegetation naturally releases exceptionally large quantities of hydrocarbons (Rasmussen 1972; Shaw et al. 1983).

Smoke clouds associated with most forest fires would be expected to encompass a much larger area, rise to a greater height, and persist longer than would fog oil clouds

generated during typical training exercises (Ward and Lamb 1970; Vines 1973b). However, forest fires create stress conditions in addition to the upset from the smoke, including increased temperatures, winds, and noise from burning twigs and leaves. Fog oil smoke would not be expected to create such additional stresses. Species adapted to such natural smoke cloud phenomena should be relatively unaffected behaviorally by the visual presence of fog oil clouds released during training exercises. Kormarek (1969) summarized responses of a number of animals (including birds, mammals, reptiles, amphibians, and insects) to fires.

Many species occupying habitats subject to frequent natural fires do not avoid the smoke cloud. Several species (including Cattle Egret, *Bubulcus ibis*; Loggerhead Shrike, *Lanius ludvicianus*; Phoebe, *Sayornis phoebe;* Wood Pewee, *Contopus virens*; Eastern Kingbird, *Tyrannus tyrannus*; Tree Swallow, *Iridoprocne bicolor*; Rough-winged Swallow, *Stelgidopteryx ruficolis*; and Purple Martin, *Progne subis*) are actually attracted to and forage within the smoke cloud. Such individuals apparently do so to feed on prey that are flushed into the open by the fire and smoke, thus making them more susceptible to capture.

Predicted Effects on Selected Species

Red-Cockaded Woodpecker (Picoides borealis)

Natural history. The Red-Cockaded Woodpecker (RCW) inhabits mature (80+ year old) open pine forests, with a preference for old-growth (>80 years) longleaf pine. The species avoids sites with mid-story deciduous trees growing among the pines. RCWs are cooperative breeders, organized into groups of 2 to 9 individuals. Group territory sizes vary from 45 to 405 ha, depending on the composition of the foraging habitat; the average sizes observed in given studies ranged from less than 50 ha to greater than 150 ha. Adult RCWs spend most of the day foraging away from the nest, routinely foraging up to 1 km from the nest tree. Territories of adjacent groups may overlap. RCWs nest in cavities excavated into the heartwood of pine trees an average height of 8 m (range, 2 to 12 m) above the ground. The circular opening extending upwards into the cavity is 7 to 9 cm in diameter; the nest cavity extends approximately 20 cm below the opening. There is an average of 7 (range, 1 to 12) cavities per group. The breeding period is from late April through July; incubation lasts 10 to 12 days and the young fledge at 26 to 30 days of age. Females disperse from the natal nest area within 3 to 4 months of hatching. Males generally disperse at this same age; however, some males occasionally remain with the natal group through the next breeding period, serving as helpers for young of the next year. The RCW feeds primarily by probing and scaling (peeling off pieces of bark) to obtain ants and other insects, spiders, and

centipedes from under the bark of trees. These invertebrates spend much of their time under the bark.

Inhalation effects. The longleaf pine habitat of the RCW represents a fire-climax ecosystem. As such, RCWs may be preadapted to frequent exposure to smoke clouds. Accordingly, it is predicted that the adults may not flee the smoked area because of the visual presence of the fog oil cloud itself. It is more likely that the birds would respond negatively to other activities associated with the smoking exercise. Smoke screening, as described here, is used in conjunction with other training activities that create potential disturbances (including the generator vehicles, troop movements, other wheeled and tracked vehicles, helicopters, and simulated artillery and small arms fire). Disturbance from these activities may result in RCWs fleeing from the immediate vicinity of the area of the most dense smoke screen cloud. Since there are no data on responses to such disturbances, it is not known if the adult birds would remain exposed to the higher concentrations of the fog oil cloud near the source.

As a result of their naturally high mobility, it is predicted that there would be short-term escape flights of adults into surrounding unaffected areas. We predict such birds would return to their original territories soon after the disturbance disappeared. During the time young are in the nest, frequent (1 to 2 per hour) flights of a few minutes duration are made back to the nest to feed the young. If adults flew into the smoke cloud to feed the young, total exposure time to fog oil still would be minimal. Although some RCWs roost on the trees at night (when nest cavities are available, adults roost in cavities; young that have fledged remain outside the cavity for the first 3 to 4 months), exposure to fog oil air concentrations would be minimal since smoking exercises are terminated at dark. Under the worst-case scenario of the adults remaining within the smoked area, total exposure time to fog oil would be at most 2 hours per training exercise, normally less.

There is the potential for young birds in the nest cavity to be exposed to inhalation effects of fog oil. Smoke exercises conducted from early May through late August would have the greatest potential to expose young RCWs to fog oil. Young assume the foraging behaviors of adults as soon as they leave the nest, flying up to 1 km from the nest tree. However, we predict the young in the nest would be exposed to very little fog oil. Although the rate of air exchange and entry of suspended materials into the cavity is unknown, the concentration of fog oil within the cavity most likely would be much less than that in the surrounding air. The generator would have to be very close ($\leq$ 10 to 20 m) and pointed upwards toward the cavity opening for there to be much fog oil forced into the cavity.

Essentially all toxicological studies of inhalation effects have involved mammals. The respiratory rate of active birds is considerably greater than that of mammals (Gill 1990); thus birds move more air (and fog oil) through their lungs per unit of time than do mammals increasing the potential for harmful respiratory effects from exposure to fog oil. The respiratory system of birds, with its air sacs, differs markedly from that of mammals. Birds expel all the air taken in during each respiration cycle, while mammals retain approximately 20 percent of the air until the next exhalation. Thus, some of the air containing fog oil would remain in the respiratory tract for a longer period of time in mammals as compared to birds. However, in birds it is not known if all fog oil is expelled during exhalation. Additionally, it is not known how these differences might affect the tolerances or actual exposure levels of birds and mammals to inhalation effects from fog oil. Whatever the differences between birds and mammals in their respiratory responses to fog oil, the results of the mammalian studies suggest that there would be few direct toxicological effects of fog oil smoke screening exercises on the RCW.

Almost all the studies that resulted in adverse effects on the experimental animals involved exposures to much higher fog oil concentrations than are predicted to occur in the field and/or were of much longer duration (e.g., several hours per day for several weeks or months) than typical smoking exercises (Liss-Suter and Villaume 1978a, 1978b; Palmer 1990; Muhly 1983; Aranyi et al. 1992). Many of the experiments that greatly exceeded the potential exposure of animals in the field (even if an animal remained in the smoke cloud during the entire training exercise) did not result in any observable acute effects. Owing to the short-term nature of training exercises using smoke screening, exposure of individual birds would not even approach that used in most of the experimental studies.

Although, researchers do not know if mammals are suitable surrogates for birds, the following toxicological studies are most meaningful in predicting the potential inhalation effects of fog oil on the RCW; none of these exposures resulted in mortality, only minor observable effects, as described.

1. A single 1-hour exposure of guinea pigs to 10 to 250 mg/m^3 light lubricating oil smoke elicited only minor adverse effects at concentrations in excess of 200 mg/m^3; (only a decrease in pulmonary compliance, i.e., decreased efficiency of gaseous exchange in the lungs, was noted; Costa and Amdur 1979). The time of exposure for this study was within that of a typical smoking exercise, but the experimental concentrations that elicited any acute effect were twice those expected in the most dense part of the smoke cloud (105 mg/m^3; see Table 1).

2. A single 4-hour exposure of albino mice (n=30) to 200 mg/m^3 of S.A.E. 10-w 20 motor oil smoke resulted in no significant adverse effects (very mild hyper-plasia of the tracheobronchial epithelium, i.e., increase in thickness of epithelium cell layer; Wagner, Dobrogorski, and Stokinger 1961). This exposure concentration/duration is approximately twice that expected to be encountered in the most concentrated area of a typical smoking exercise (see Table 1).
3. A 6-hour exposure per day of Golden Syrian hamsters (n=218) and rabbits (n=46), 5 days per week for 26 months, to 100 mg/m^3 mineral oil smoke resulted in only minor effects (no major lung tissue response; presence of oil macrophages [large amoeboid cells engulfing oil droplets] in alveoli; no other pathological findings; Wagner, Wright, and Stokinger 1964). While this exposure concentration is approximately that predicted for the most dense part of the smoke cloud, the total exposure time is equivalent to four 90-minute smoking exercises per day for more than 2 years.
4. A 30-min/hour exposure of mice (n=80) for 100 days to 132 mg/m^3 of S.A.E. 10 oil smoke elicited only minimal effects (gradual oil accumulation in lung macrophages in peripheral and subpleural alveoli; no free oil; oil macrophages in tracheobronchial lymph nodes; minimal toxicity; Lushbaugh and Cannon, 1942). This exposure rate is only slightly greater than the maximum predicted field exposure. However, the total exposure period is equivalent to eight 90-minute training exercises per day for 100 days.
5. A 30-min/hour exposure of mice (n=250) and rats (n=80), for 343 days, to 63 mg/m^3 of SGF No. 1 (similar to SGF No. 2, but of higher viscosity) smoke resulted in only minor pulmonary problems (no lipoid pneumonia, i.e., inflammation resulting from exposure of lung tissues to oil, and little evidence of other inflammation; macrophages with dispersed oil droplets were seen throughout the lungs; Lushbaugh, Green, and Redemann 1950). While the concentrations in this study are realistic, the duration was equivalent to eight 90-minute smoking exercises per day for almost a year.
6. A 6-hour exposure of mice (n=250) for 5 days per week for 16 months, to 100 mg/m^3 of mineral oil smoke resulted in only minor effects (excess of pulmonary tumors; oil deposition in mediastinal and peribronchial lymph nodes; no excess pneumonia; Wagner, Wright, and Stokinger 1964). This concentration is realistic, but the exposure time represents a total of 1300 typical smoking operations in a site within 15 months.
7. While a single 3.5-hour exposure of rats to 1000 mg/m^3 of fog oil smoke resulted in no mortality, a 6-hour exposure resulted in death of all the rats (Selgrade et al., 1987; Grose, Selgrade, and Davies 1986). Although the exposure times in these experiments were only approximately 2 and 4 times those of typical smoking exercises, the concentrations were almost 10 times those expected in the field (see Table 1).

8. A 3.5-hr/day exposure of rats to 0.5 or 1.5 mg/L of SGF No. 2 smoke, 4 days a week for 4 or 13 weeks caused minimal pulmonary effects (Grose et al. 1985). There were no observable changes in immunological parameters or clinical chemistries. Both the concentrations and exposure times used in this study greatly exceeded those expected in training exercises.

Results of exposures to even greater concentrations are as follows:

1. Mice treated to a single 2-hour exposure of 4330 mg/m^3 S.A.E. 10 motor oil smoke experienced oil retention in terminal bronchioles and alveolar ducts, vigorous oil phagocytosis (engulfment of oil droplets by white blood cells). Two studies were conducted (n=6 in each). One resulted in 2 deaths, the other none (Shoshkes et al., 1950). Note, however, that motor oils have additives that increase their toxic effects.
2. A 90-hour exposure of mice (n=13) to 4500 mg/m^3 (total, intermittent exposures) to S.A.E. 10 motor oil smoke resulted in 3 deaths; extremely heavy oil retention in all divisions of the respiratory tree; pneumonia; and coalescence of oil into giant droplets (Shoshkes et al., 1950).

Ingestion effects. Since the prey of the RCW are found under the bark of trees, they would have little contact with fog oil; the bark would protect the prey from the fog oil during smoking operations. The birds are not expected to ingest significant quantities of fog oil while prying off pieces of bark to get to the insects. Likewise, the food of the bark invertebrates would be minimally contaminated with fog oil. Therefore, there is predicted to be little opportunity for RCWs to acquire fog oil through food chain concentration. As suggested above, disturbance from other aspects of the training exercises may "spook" individual RCWs from the vicinity of the most concentrated fallout, even if such deposition should occur. Assuming there would be some time (1 to 2 hours) before all training disturbances (troops, vehicles, etc.) left the vicinity of the more heavily smoked site, it is predicted that much of any fog oil that did deposit on the trunks of trees would have evaporated before RCWs returned to feed in their territories.

The available experimental toxicological data are inadequate to provide a realistic assessment of the potential ingestion effects of fog oil or related petroleum products on the RCW (Driver et al. 1992; Liss-Suter and Villaume 1978a, 1978b). Although most toxicological ingestion studies involved avian species (Muhly 1983), the quantities ingested that resulted in observable adverse effects on the experimental animals were greatly in excess of what could be expected to be ingested by the RCW. Further, most of the ingestion studies involved diesel fuel, which has been shown to display greater toxicological effects than does fog oil (Liss-Suter and Villaume 1978a).

The few studies that are applicable in evaluating ingestion effects of fog oil on RCW have shown that test birds (quail and ducks) and mammals (mice) are tolerant of daily consumptions of 20 to 24 ml/kg body weight (= 17.0 to 20.4 g/kg; 1 ml = 0.85 g) lubricating oil and diesel fuel (Hartung and Hunt 1966; Brahmachari 1958). This is equivalent to a total daily consumption of 0.8 to 1.0 g by a 50 g RCW, the upper weight range for individuals of this species (the presumption is that exposure above 1.0 g is adverse). Ingestion of 3.5 mg/kg per day interrupted egg production and disrupted embryonic development (via either embryolethal or embryotoxic effects) in quail and chickens (Liss-Suter and Villaume 1978a). Ingestion of No. 2 diesel fuel oil has also been shown to cause thinning of the egg shells, resulting in breaking of the shells (Liss-Suter and Villaume 1978a). Given the lack of evidence for deposition of fog oil upon the vegetation, it is unlikely that either adult or nestling RCWs would ingest toxic quantities of fog oil.

Since the birds are predicted to spend little time within the smoke screen cloud, insignificant quantities of fog oil would be expected to adhere to the feathers. In addition, given that little fog oil is presumed to deposit on the vegetation, it is questionable that fog oil would adhere to the feathers of the RCW. Ducks exposed to oil spills have been found to ingest approximately 20 percent of the oil on their feathers during preening. For a RCW to obtain 1 g of oil (the quantity presumed to result in adverse effects; see above), a total of 5 g of oil would have to settle on its feathers. This is equivalent to that predicted to settle on an area of 1.6 m^2 at 100 m and 50 m^2 at 1000 m from the source, if the fog oil did deposit from the air. Thus, it is unreasonable to expect the RCW to ingest sufficient quantities of fog oil from preening to cause adverse toxicological effects.

Other effects. Coating of eggs by oil has been shown to adversely affect hatchability. Pheasant eggs sprayed with sufficient fuel oil mist to wet the eggs failed to hatch (Kopischke 1972). When only 2 percent of individual duck eggs were coated with diesel fuel oil, embryonic developmental problems resulted (Driver et al. 1992). As indicated earlier, it appears unlikely that sufficient quantities of fog oil would penetrate into nest cavities to cause significant counting of eggs. Further, there is no information regarding the effects of an oil coating equivalent to the small quantities that might be deposited on RCW eggs from fog oil clouds.

Temporary movement of RCW from their territories into the territories of adjacent groups is predicted to have little disruptive effect on social organization or mating systems of RCW populations. Territories of adjacent groups routinely overlap; as such, individuals are used to the sporadic presence of intruders. Further, owing to the large territory size of a group in relation to the total area typically smoked, relatively few individuals would be displaced during a given training exercise. There should not be

a large influx of birds into surrounding group territories. The responses of individuals to the fog oil clouds may vary depending upon season, age, reproductive status, and degree of exposure to fog oil clouds.

Assumptions that need testing. Based solely on evaluation of the anecdotal observations and data summarized above, it would appear that if the smoke generators were located at least 100 m from the nest trees of a group, there should be no serious acute adverse effects of fog oil smoke screens on the RCW. However, data are inadequate to test these assumptions. We are lacking the basic information to present an accurate evaluation of the effects of fog oil smoke screening training exercises on RCW populations. In particular, data are needed to test the assumptions that:

1. There is insufficient fog oil deposition onto the trunks of trees to result in adverse ingestion effects.
2. The feeding behavior of the RCW (on invertebrates that live under the bark of trees), minimizes potential ingestion effects, even if fog oil deposits onto the bark (i.e., the bark protects the prey animals and their food from fog oil).
3. The duration of smoking exercises is too brief and air concentrations of fog oil during the exercises are too low to result in adverse inhalation effects.
4. Offspring living in the nest would not be exposed to fog oil.
5. Hatchability of eggs within the smoked area is not reduced.
6. Conduct of training exercises at a specific site are so infrequent as to minimize the potential for chronic adverse effects on the RCW.
7. Activity patterns and foraging territories of the RCW are such that the exposure risk of individual birds would be minimal; further, owing to other disturbances, most birds would be chased away from the smoke for the brief time part or all of their territories were engulfed by the fog oil cloud.

Eastern Indigo Snake (Drymarchon corais couperi)

Natural history. The Eastern Indigo Snake occurs in open longleaf pine-grass habitat, similar to that occupied by the RCW. Individuals use the deep underground burrows of the Gopher Tortoise for resting sites when not active on the surface. Above-ground activity of the Eastern Indigo snake is restricted to the forest floor. Food consists primarily of other reptiles (lizards and snakes); relatively few mammals or birds are eaten.

Inhalation/direct effects. There are no data available from which to estimate possible inhalation effects from fog oil. Further, we do not know how much, if any, of the fog oil cloud penetrates into the burrows used by the Eastern Indigo Snake. Since the fog oil cloud rapidly dissipates and rises from the surface, it is doubtful the snakes would

be exposed to sufficiently high concentrations of fog oil long enough for toxicological effects to occur. If the assumption is correct that fog oil deposits on the litter surface are insignificant, there should be no direct effects of the fog oil on the Eastern Indigo snake; there would be no deposit onto the snakes themselves.

Ingestion effects. Fog oil would be ingested by the Eastern Indigo Snake only through bioaccumulation effects. If the above assumptions regarding minimal deposition of fog oil to the surface and little incorporation of fog oil into the leaf litter layer are correct, it is unlikely that fog oil would be present in the food of the Eastern Indigo Snake. Even though prey lizard species feed primarily upon insects living on or in the leaf litter, there would be little likelihood of such insects and other invertebrates accumulating significant quantities of fog oil. Other snakes in the habitat that serve as prey (e.g., coachwhip snake) would also be expected to contain little fog oil. Their food is taken from the forest floor, where there should be little opportunity for accumulation of fog oil.

Assumptions that need testing. The above predictions that the Eastern Indigo Snake would not be adversely impacted by usual tactical smoke screening exercises are all based on untested assumptions regarding concentrations and distribution of fog oil in the environment. The predictions that both inhalation and ingestion effects would be minimal cannot be verified with the available data. In particular, we need data to test the assumptions that:

1. Duration of exposure to fog oil while active on the surface is too short to result in adverse inhalation effects.
2. Fog oil does not penetrate into the underground Gopher Tortoise burrows used by the Eastern Indigo Snake.
3. Prey of the Eastern Indigo Snake would not contain toxicologically significant concentrations of fog oil.

Gopher Tortoise (*Gopherus polyphemus*)

Natural history. The Gopher Tortoise inhabits sandy areas where the water table is well below the surface. In most of the Southeast it is a characteristic species of the open longleaf pine-wiregrass habitat. Tortoises excavate and permanently occupy extensive burrows that extend to a depth of 1 to 3 m and are up to 10 m long. Depending on the size of the tortoise, the surface entrance is 5 to 15 cm high and 18 to 30 cm wide. The burrow angles 17 to 39 degrees downward from the surface. There is an enlarged resting chamber at the end of the burrow. The tortoises are diurnal in habits, retiring to their burrows at night and during periods of adverse meteorological conditions. Females lay 4 to 7 eggs in small excavations 15 cm below the surface. The

young emerge in August and September and are secretive in habits. Food consists almost entirely of grasses and leaves of forbs.

Inhalation/direct effects. As in the case of the Eastern Indigo Snake, there are no data from which to estimate inhalation effects from fog oil on the Gopher Tortoise. Based on burrow dimensions, we assume that there would be little penetration of fog oil into the burrow system of the tortoise. Inhalation effects would be possible only during those brief times the animals were exposed to a fog oil cloud while active on the surface. Since fires (and thus smoke) are a common phenomena of the Gopher Tortoise habitat, we predict individuals would not retire to their burrows in response to exposure to the fog oil cloud. Such exposures are predicted to be too transitory to elicit any toxicological effects. Given the small amount of exposed integument and the prediction that significant quantities of fog oil do not deposit on the surface, there should be no direct effects of the fog oil. Developing eggs would be protected from exposure to fog oil even if it should deposit from the fog oil cloud.

Ingestion effects. If the prediction that fog oil does not deposit onto the surface is verified, there should be no adverse ingestion effects. Food chain concentration would not be a factor since the tortoises feed on grasses and leaves.

Assumptions that need testing. The predictions of insignificant effects of fog oil released during usual tactical smoke screening exercises on the Gopher Tortoise cannot be verified from existing data. The following assumptions need to be tested:

1. Duration of exposure of tortoises to fog oil smoke while active on the surface would not be sufficient to result in adverse inhalation effects.
2. Fog oil smoke does not penetrate into the resting chambers at the end of the burrows.
3. Food of the Gopher Tortoise does not contain toxicologically significant concentrations of fog oil.

Bachman's Sparrow (Aimophila aestivalis)

Natural history. Bachman's Sparrow inhabits the longleaf pine habitat, but is most abundant where a dense understory of herbaceous vegetation is present. These birds are ground nesters. Territories average only 0.25 ha. Bachman's Sparrow forages on the forest floor or in grassy openings, feeding mainly on seeds, especially those of grasses. The young are fed insects. Adults forage throughout the day when young are not present; when young are in the nest, most foraging takes place during the first 5 hours following sunrise. The incubation period is 14 days and the young fledge at 10 or 11 days of age. Bachman's Sparrows most likely are used to (or preadapted)

exposure to smoke conditions. If so, adults may not be driven from their territories by the presence of smoke alone. Other disturbances associated with the training exercise, as indicated earlier, are more likely to scare the birds off their territories.

Inhalation effects. Even if Bachman's Sparrows remain on their territories, it does not appear they would incur serious toxicological risks. As described for the RCW, air concentrations of fog oil even within 100 m of the generator are estimated to be less than those predicted to result in acute adverse effects, given the typical short periods of smoking.

Ingestion effects. Since adult Bachman's Sparrows feed primarily on seeds, their food sources may not be greatly contaminated with fog oil. Even should all the fog oil deposit from the air, we assume insignificant quantities would settle on and be ingested with the seeds. Unfortunately, data are not available to estimate the amount of fog oil that might be ingested when feeding on seeds.

Young Bachman's Sparrows are fed primarily insects and thus may be more susceptible to ingestion effects than are adults. The adults carry the insects to the young in their bills, rather than swallowing and latter regurgitating the insects, and thus would not ingest fog oil while feeding the young. Estimates of the maximum quantities of fog oil that might be ingested by nestlings are based on (1) the assumption that all the fog oil present in the smoke cloud deposits from the air onto the vegetation, (2) deposition onto the vegetation is the same as that on the substrate surface, (3) fog oil deposition onto the vegetation would be ingested by and accumulated in the prey insects, (4) an average weight of 10 g for the young (adult weight is approximately 20 g), and (5) ingestion of a total of 0.2 mg/day of fog oil may result in adverse effects on the young (based on an upper level of tolerance of 20.4 mg/kg/day, as estimated earlier). Note, this assumption does not take into account any differences in the toxicological effects of fog oil on young and adults; such data are not available.

The data in Table 1 were used to estimate the total potential fog oil accumulation per square centimeter of vegetation. From these data we estimated the square centimeter of leaf material that the foliage feeders (eaten each day by the nestlings) would have to consume to accumulate at least 0.2 mg of fog oil. These estimates vary from consumption of approximately 0.1 m^2 at 100 m to 3.0 m^2 at 1000 m from the source at concentrations estimated to be present 1 hour following the smoking exercise. The equivalent values for 1 week following smoking would be 0.4 m^2 and 13.3 m^2. We do not have data regarding the amount of foliage consumed by individual prey, or the number of such prey fed to Bachman's Sparrow nestlings per day. However, it does not appear that enough foliage feeders would be consumed for the young sparrows to ingest quantities of fog oil approaching that necessary to elicit toxicological effects.

Other effects. If the birds avoid the smoke cloud by fleeing their territories, such displaced birds would intrude into the territories of adjacent pairs. Because of the very small territory size of Bachman's Sparrow, typical smoking exercises would be expected to cloud areas that would encompass the territories of a large number of pairs. The actual number of pairs impacted obviously would depend on the abundance of the species in the specific site being smoked. If a sufficiently large number of pairs were displaced for a considerable period of time, the social organization and mating system could be disrupted, thus adversely affecting reproductive success of the population. Under such conditions smoking could, therefore, have an adverse effect on population demography of Bachman's Sparrow. However, such a problem would appear to be minimal, given the short duration of smoking exercises and the rapid dissipation of the fog oil once smoking has ceased.

If nesting adults were driven from the breeding territory during smoking operations, we might expect greater loss of eggs and nestlings to predators, depending on the amount of time required for the adults to return to their territories in comparison to movement of nest predators into the site. Even if not predated upon, exposure of eggs to ambient temperatures during the time the adults were away may adversely affect hatching success and nestling survival. Also, the exposed eggs may be subjected to oil deposition that may adversely affect hatching success. Young deprived of adult brooding may also suffer from exposure effects, including deposition of fog oil on their bodies.

As indicated earlier, Bachman's Sparrows have had a long evolutionary history of association with smoke. It is doubtful, therefore, that presence of the smoke per se would result in temporary displacement of territorial birds. The other activities associated with the training exercise are more likely to chase adults from their territories. Any adverse effects resulting from exposure of eggs and young to fog oil would be the same, however, regardless of why the adults leave their territories.

Another factor that must be considered is the potential effects of the fog oil on the insect populations. Oils have been used as insecticides in the past (as summarized by Liss-Suter and Villaume 1978a); thus, there may be a reduction in insect populations and in turn a reduction in food availability for the adults and young should fog oil deposit on the vegetation. This would exacerbate any direct adverse effects of the fog oil on Bachman's Sparrow populations. However, we predict that the amount of fog oil that deposits on the vegetation would be insufficient to adversely affect the insect populations.

Assumptions that need testing. The predictions that Bachman's Sparrow would be minimally impacted by fog oil smoke screening are based almost entirely on the

assumption that fog oil does not deposit from the smoke cloud. Only if all the fog oil deposited from the smoke cloud, could Bachman's Sparrow be impacted by fog oil smoke screening training exercises. Even then, the quantities involved are predicted to be too low to elicit toxicological effects. Temporary dislocation of adults from their territories may also have adverse effects on the population. However, preadaptation to smoke conditions is predicted to reduce the potential for such dislocations by the smoke cloud itself. The following assumptions therefore need to be tested to determine the impact of fog oil smoke screening exercises on Bachman's Sparrow:

1. Fog oil concentrations are too low and of too short duration to result in inhalation effects.
2. Insufficient fog oil deposits on the foliage and grass seeds for there to be ingestion effects.
3. Adults are not displaced from their territories by the fog oil cloud itself, but by other activities associated with the training exercise.
4. Foliage-feeding insect populations are not reduced in areas covered by the smoke cloud.

Gray and Indiana Bats (*Myotis grisescens* and *Myotis sodalis*)

Natural history. The natural histories of these two species of bats are sufficiently similar that they can be considered together. Both species of bats are nocturnal feeders, emerging at dusk and returning to their daytime roosts at dawn. The Gray Bat spends the day roosting in caves. The Indiana Bat secrets itself under the loose bark of trees or in cavities in trees during the breeding period; at other times it hangs inside caves. Both species feed on flying insects such as moths, mayflies, and caddisflies.

Inhalation effects. Since smoking exercises are conducted only during the daylight hours, neither species would be expected to be exposed directly to the fog oil cloud. It is also unlikely that toxicologically significant concentrations of fog oil would penetrate into the roosting sites inside caves. Neither would one expect the Indiana Bat to be exposed to significant concentrations of fog oil while in the maternity trees. However, there are no data available regarding amount of air exchange within the spaces under the bark or in the tree cavities.

Ingestion effects. The only way either species of bat could ingest toxicologically significant quantities of fog oil would be through food-chain concentration. Although some of the larvae of the insect prey may be exposed to fog oil if the oil deposited from the smoke cloud onto the vegetation (and became incorporated in the water, in regard

to the aquatic insect prey), the adults would not be expected to ingest significant quantities of fog oil.

Assumptions that need testing. Data are needed to test the assumptions that:

1. Fog oil from smoke screening exercises does not enter into caves where the bats hang during the day or under the bark and into cavities of nursery trees of the Indiana Bat.
2. The prey of the bats does not contain sufficient quantities of fog oil to cause toxicological effects when ingested.

Flatwood Salamander and Striped Newt (Ambystoma cingulatum and Notophthlamus perstriatus)

Natural history. These two species have similar habits and occupy similar habitats and are thus considered together. During most of the year adults of the two species live within the leaf litter and under debris in forested habitats (Dodd 1993). When temporary woodland pools fill with water in the spring, the adults move into the pools to mate and lay eggs. Adults of the striped newt remain in the pools until they dry up, usually late spring-early summer. Flatwood Salamanders move back to the forest floor after mating and laying eggs. The larvae of both species metamorphose and move into the terrestrial habitats as the pools dry up.

Inhalation/Direct exposure effects. Adults of neither species should be exposed to air containing fog oil while in the protected air spaces within the leaf litter. Eggs (which are attached to submerged vegetation or debris) and larvae, on the other hand, potentially would be susceptible to fog oil while within the aquatic habitat. However, it is assumed that significant amounts of fog oil do not disperse into the water, even if any were to deposit on the surface of the pools. As indicated above, any oil that might deposit on the surface of temporary pools is predicted to remain on the surface until it evaporates.

There are no toxicological studies of the effects of fog oil on larval salamanders. The most applicable data are from small fish (fingerling American Shad and various species of minnows). Most of these experiments used No. 2 diesel fuel oil, which is more toxic than SGF No. 2 (Liss-Suter and Villaume 1978a). Further, the experimental concentrations were well in excess of even the predicted worst-case scenario derived from the models. Assuming all the oil deposits on the surface and becomes dispersed in the water column, the greatest potential concentration in the field was estimated to be 6 g/m^3; most estimates range from 0.1 to 3 g/m^3 (Table 1). The experimental concentrations resulting in 50 percent mortality of small fish ranged from 167 to

260 g/m^3 with exposure times of 24 to 96 hours (summarized by Muhly 1983). Since scales on the fish would reduce absorption of fog oil through the integument, we assume that eggs and larval and adult salamanders would be more susceptible to fog oil than would small fish; there are no data to support this assumption. Given the predictions that (1) fog oil does not deposit from the air, and (2) if it did, it would not become dispersed into the water column, the impact of fog oil smoking on the eggs and larvae of these two salamanders is predicted to be minimal.

Ingestion effects. Adults presumably would not be at risk from ingestion of fog oil within their food. Both species feed on small invertebrates, including small insects and worms, living within the protected moist decomposing leaf litter layer. As indicated above, the substrate, and thus the food of these prey species, is predicted to contain insignificant quantities of fog oil. Owing to the assumption that fog oil does not disperse into the water of shallow pools, it is also unlikely the prey of the larval salamanders would acquire fog oil through food chain concentration.

Assumptions that need testing. From the above evaluations, it would appear that there would be no adverse effects of typical smoking exercises on either species of salamander. So long as there were no vehicular traffic within the habitat (which would mix fog oil on the surface of the litter with the decaying litter below), adults living within the leaf litter layer would be isolated from any deposition of fog oil that might occur. Data are needed to test the following assumptions:

1. Fog oil neither deposits onto nor penetrates into the leaf litter layer.
2. Fog oil neither deposits onto nor becomes incorporated into the water.
3. Prey species of the adults and larvae do not contain sufficient quantities of fog oil to elicit toxicological effects.

Golden-cheeked Warbler and Black-capped Vireo (*Dendroica chrysoparia* and *Vireo atricapillus*)

Natural history. The habitat terrain occupied by these two species and their natural history are sufficiently similar that they are considered together. Although the Golden-cheeked Warbler (GCW) and Black-capped Vireo (BCV) occupy different habitat types (mature and second growth juniper-oak woodlands, respectively), on Fort Hood, TX (the installation on which they occur that is most likely to be used for training exercises using smoke screening) they both occur primarily on steep slopes and other rugged terrain.

Territory size of the GCW is approximately 2.5 ha. The nests of the GCW are constructed an average of 4.6 m above the ground level. Adults begin arriving at Fort

Hood in early March and have left by the end of July. The nesting period is May through June. The incubation period is 12 days and the young fledge at 9 days of age. Females remain on the nest 75 percent of the daylight hours during this time. Food consists primarily of insects, including beetles, lepidopteran caterpillars, homopterans, and hemipterans and spiders. Most of these are gleaned from the foliage of trees.

The BCVs arrive at Fort Hood in mid March and have left by the end of September; the breeding period is from early April through early July. BCV territories encompass an average of 1.5 ha; nests are located 0.5 to 1.5 m above the surface. The incubation period and nesting time are similar to those of the GCW. Food consists mainly of lepidopteran and coleopteran larvae gleaned from the foliage of trees; some grasshoppers are also eaten.

Inhalation effects. As discussed for the RCW, air concentrations of fog oil are predicted to be sufficiently low at distances more than 100 m from the source as to have little effect on birds remaining within the smoke cloud. Given that the woodland habitat of the GCW and BCV is located on steep slopes and uplands, it is doubtful that much of the more dense smoke cloud from training exercises would encroach into the breeding territories of either species. Most training activities on Fort Hood involve armored units. Training programs and associated smoking exercises most likely would be restricted to the flat lands; the steep slopes occupied by the warblers and vireos would not be used. Generators used in the training would be expected to be maneuvered at least 100 m from the nearest slopes, i.e., breeding territories. If so, there should be little possibility of toxicological effects from inhalation of fog oil for either species.

Only if the generators were operated much closer than 100 m to the steep terrain habitats of the two species, could either species be adversely affected. If the fog cloud encroached on the slopes, both adults and nestlings might be subject to inhalation effects. The severity of any effects would depend on the concentration of the fog oil in the cloud.

Ingestion effects. If the fog oil cloud covered the territories of breeding pairs, the calculations used for estimating worst-case ingestion effects for nestling Bachman's Sparrow can also be used for these species. Adults of both GCW and BCV weigh approximately 10 g. Thus, the values given for young Bachman's Sparrows (which were based on a 10 g body weight) would apply for adult GCW and BCV. Assuming an average body weight of 5 g, nestlings of these two species would have to ingest only half the amount of fog oil as would adults to experience toxicological effects. Whether or not ingestion effects should be considered to have an adverse effect on GCW and BCV depends upon (1) the extent of encroachment of the smoke cloud into the steep

slope woodland habitats of the two species, (2) whether any fog oil deposits on the vegetation, and (3) whether the fog oil accumulates in the prey invertebrates.

Other effects. As in the discussion of Bachman's Sparrow, dislocation of adults from the breeding territories has the potential to disrupt social structure, and in turn reproductive success of the population. Unlike the RCW and Bachman's sparrow, neither the GCW or BCV are preadapted for tolerating smoke; vegetation fires are not a characteristic of the habitat of the two species. The territories of these two species are approximately 6 to 8 times larger than those of the Bachman's Sparrow. Thus, fewer individuals of GCW and BCV potentially would be dislocated into territories of adjacent pairs than in the case of Bachman's Sparrow. Further, presence of the fog oil cloud would be so brief as to minimize disruptive effects on social organization and mating system of the GCW and BCV.

If breeding adults are temporarily displaced from their breeding territories by the smoke cloud, the eggs and nestlings may be exposed to greater predation risk during the time of abandonment. Also, absence of brooding by the adults may result in greater risk of exposure of eggs and nestlings to smoke, disruption of embryonic development, or thermal regulatory problems for the nestlings, each of which would adversely affect recruitment of young into the population. Again, it would seem likely that the adults would return soon enough to minimize these potential effects.

Should fog oil depsoit on the vegetation and reduce foliage insect populations, the food supply for both species may be adversely affected. This could have a negative effect on GCW and BCV population demography and exacerbate any other effects resulting from exposure of the birds to fog oil smoke. As indicated previously, however, there is no indication of deposition of fog oil onto the vegetation.

Assumptions that need testing. Without information regarding the location of smoke screening training exercises, we cannot provide a realistic evaluation of the effects of such activities on either the GCW or BCV. Accordingly, data are needed to test the following assumptions:

1. Training activities and the resulting location of the smoke generators are restricted to lowlands away from the hillsides; the fog oil cloud would not cover the habitat of either species.
2. Even if the fog oil cloud covers the territories of the GCW and BCV,

    a. There is little or no deposition of fog oil onto the vegetation.

b. Foliage-feeding insect populations are not reduced in areas covered by the smoke cloud.
c. Any fog oil that deposits onto eggs has no effect on embryonic development.

Sage Grouse (Centrocercus urophasianus phaios)

Natural history. Sage Grouse occupy open sagebrush habitat. Males establish and occupy breeding leks (strutting grounds) in early spring, between mid March and late April. Females are attracted to a given male's lek for mating. After mating, females move away from the lek to make their nests; most nests are located within 1 to 2 km of the lek. After the chicks hatch, the females and brood routinely forage over an area with a radius of 0.5 to 1.0 km. After leaving their leks, males forage over an area in excess of 1 km from the lek. Daily movements of males and females during the winter are at least 0.5 to 1.0 km, sometimes exceeding 2.5 km. The total incubation period, the time from laying of the first egg to hatching of the last egg, is approximately 26 days. Food of the adults consists almost exclusively of leaves of sage plants. The young are fed primarily ants, beetles, weevils, and grasshoppers.

Inhalation effects. Given the wide ranging activity of the adults and the female with her brood, the grouse most likely would move out of the clouded area should fog oil be irritating. As in the case of the GCW and BCV, the Sage Grouse should not be pre-adapted to tolerating smoke clouds; vegetation fires are not a characteristic of the habitat of this species. A critical time might be when the female is still incubating the eggs. The female and young that have already hatched might be subject to inhalation effects at this time. However, fog oil concentrations in the air more than 100 m from the source are predicted to be sufficiently low as not to result in toxicological effects.

Ingestion effects. If the prediction that fog oil remains suspended in the air until it evaporates is correct, the Sage Grouse should encounter no toxicological effects from ingestion. Bioaccumulation would not be a factor in the ingestion of fog oil by adults even if the fog oil depoisted onto the vegetation. Adults would ingest only fog oil that settled on the sagebrush leaves. Assuming an average adult weight of 2.5 kg for males and 1.3 kg for females, we estimate approximately 50 and 25 g/day of oil would have to be ingested by males and females, respectively, to elicit adverse toxicological effects (based on 20.4 g/kg body weight). In order to ingest this quantity of fog oil, if all the fog oil in a smoke cloud deposited on the vegetation, the males would have to consume 25 m^2 of vegetation daily 100 m from the fog oil source and 758 m^2 1000 m from the oil source. Comparable values for females would be 12.5 m^2 and 379 m^2. These represent unreasonable quantities of daily food intake for adults. Since young are fed insects, bioaccumulation effects may increase the risk from ingestion of fog oil for the young. Due to the rapid growth rates of young, it is not realistic to attempt to estimate the

quantities of oil-coated vegetation that would have to be consumed by the insects fed to the young, such that toxicological effects resulted. However, there is no evidence for bioaccumulation of fog oil under natural conditions.

Other effects. Smoking exercises conducted during the mating period may drive males and females off the leking sites, thus disrupting reproduction. If females were temporarily driven away from their nests during the period of nesting, increased loss of eggs and nestlings to predators may be incurred. In addition, should the fog oil deposit onto the eggs, hatchability may be adversely affected. If the insect populations declined because of the presence of an oil film on the vegetation, the reduced food supply to the young may exacerbate other adverse effects from the fog oil. None of these factors are presumed to be important, however, given the prediction that fog oil does not deposit to the surface.

Assumptions that need testing. The high mobility of the adults and newly hatched broods would allow most birds to avoid inhalation effects. If the assumption that fog oil does not deposit from the cloud is correct, it appears that the Sage Grouse would not be affected seriously by fog oil smoke screening training. Rapid evaporation of any oil that might deposit would likely result in insignificant ingestion effects. Data are needed to test the following assumptions:

1. Males would not permanently abandon their leks if exposed to the fog oil cloud during the mating period.
2. Sage Grouse adults (including females with clutches) would avoid the fog oil cloud by moving out of the immediate area of the cloud.
3. Fog oil concentrations in the air would be too low to result in toxicological effects on the adults or young, should they remain in the smoked area.
4. Too little fog oil would deposit on the vegetation to result in toxicological effects, either directly through feeding on the vegetation by the adults, or through accumulation in insects fed the young.
5. Too little fog oil would deposit on exposed eggs to result in toxicological effects.

Plants

As indicated earlier, a number of threatened, endangered, and candidate plant species are found on Army installations. Data are inadequate to estimate possible effects of fog oil on these species. Most conclusions regarding potential effects of petroleum products are based on application of agricultural oil sprays in concentrations of 1 to 50 percent when used as insecticides (Liss-Suter and Villaume 1978a). Further, data are available only for citrus trees, pine, cedar, and a number of species of broad leaf foliage trees, including aspen; sugar, silver, and Norway maples; tulip; oak; and ash.

Data were also obtained from vegetable crop species such as turnips and beans. Although such exposures to petroleum sprays, including kerosene, at these concentrations did result in adverse effects on the plants, we cannot extrapolate these results to effects that might be incurred by exposures to lesser concentrations of fog oil.

The only study of effects of fog oil on plants is that of Cataldo et al. (1989). This study used a wind tunnel in which to expose seedlings of ponderosa pine and short needle pine, tall fescue, and bush bean plants to fog oil concentrations of 800 mg/m^3 for 2, 4, 6, and 8 hours. They did not measure deposition of fog oil onto the plants. Of the species tested, effects of fog oil on tall fescue and bush beans are most applicable to native threatened and endangered herbaceous plants. Responses of both species involved primarily old plant growth tissues; newly forming tissue were little affected. Observations taken 21 days after a 2-hour exposure revealed a maximum of 5 percent old growth tissues displaying chlorosis or tip burn. After a 4-hour exposure, 5 to 25 percent damage was observed; after 6 and 8 hrs of exposure, 75 to 95 percent damage was observed 21 days later. This damage was soon repaired by new growth. Seed pods of the bush bean developed normally at the highest exposures.

Based on the responses of these species, it would appear that any fog oil damage to plants would be minimal at distances beyond 200 m from the generator. If fog oil does not deposit from the air, we would expect no serious adverse effects on threatened and endangered plant species. These assumptions remain to be tested.

4 Summary and Recommendations

Summary

This report provides a preliminary evaluation of the potential impacts of fog oil smoke on threatened and endangered species. The analyses performed were based on the best information available on the use and resulting concentrations of smoking materials under worst-case scenarios. The results suggest that acute effects on selected species are likely to be minimal. The analyses, however, are based on several important assumptions. Testing these assumptions through future research efforts will be essential to completing a realistic assessment of the impact of fog oil smoke on threatened and endangered species.

Recommendations

Major Assumptions That Need To Be Tested

The most critical information needed to test the assumptions listed in the previous chapter are field measurements of environmental concentrations and fate of the fog oil in the smoke cloud associated with both typical and worst-case smoking exercise scenarios. All the predictions in this report are based on models, untested assumptions, and anecdotal observations of fog oil clouds resulting from typical smoke screening exercises. Further, almost all the toxicological data are from studies that used inappropriate concentrations and exposure times. Specific data needed to test the assumptions regarding potential effects of fog oil smoke screening exercises on threatened and endangered species are listed at the end of each species account. The following summarizes the most important assumptions that need to be tested and other basic data that are necessary in order to evaluate the effects of fog oil smoke screening on threatened and endangered species.

Environmental Concentrations

1. Air concentrations of fog oil smoke at varying distances from the source are similar to those predicted by the mathematical models.

2. Fog oil dissipates from the smoked area within a few minutes following termination of the exercise (under usual atmospheric conditions).
3. Most, if not all, of the fog oil evaporates, rather than depositing onto the substrate surface, water surface, foliage, and bark of trees, or onto the fur and feathers of animals.
4. There is rapid evaporation of any fog oil that does deposit on the surface of litter, vegetation, water, or animals.
5. Fog oil does not become incorporated into the water column of small, shallow pools.
6. Very little, if any, fog oil penetrates into the nest cavities of RCW.
7. Very little, if any, fog oil enters the underground burrows of the Gopher Tortoise used by the Eastern Indigo Snake.
8. The litter layer and bark of trees are effective in reducing the exposure of litter- and bark-dwelling animals (including the Indiana Bat) to fog oil.

In addition, the following data are needed:

1. Amount of fog oil present in foliage-feeding invertebrates.
2. Amount of oil film that would be deposited on exposed bird eggs, both in open nests and those in RCW cavities.

Toxicological Data

Inhalation/direct effects. Data are needed regarding:

1. Toxicological responses of surrogate species to fog oil concentrations recorded within the smoked area and for duration of exposure as would be encountered by individuals in the field.
2. Effects of oil film, using quantities presumed to deposit onto exposed eggs, on hatchability of bird eggs.
3. Toxicological tolerance data for larval salamanders using fog oil concentrations recorded in the field, (but only if it is found that fog oil becomes incorporated into the water of temporary pools).

Ingestion effects. If field data show that fog oil does deposit on the vegetation, is incorporated into the water column, and/or is taken up by invertebrate prey of the various species, it will be necessary to obtain ingestion toxicity data using the range of environmental concentrations recorded from field studies.

Behavior of Birds

If the toxicological studies indicate possible detrimental effects under the actual exposure regimes, the following field data are needed regarding the behavior of the various species of birds in response to smoke screening operations.

1. Avoidance of the fog oil smoke cloud by temporarily fleeing the smoked site.
2. If the birds do avoid the smoked area, the length of time until individuals return to their home ranges.
3. If adults remain in the smoked area, record whether on the nest or flying around within the smoke cloud.

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